# Assessing Aerosol Data Assimilation Products Using DIAL/HSRL Measurements


**Richard Ferrare[1], John Hair[1], Sharon Burton[1], Anthony Notari[1]
Chris Hostetler[1], Syed Ismail[1], Amin Nehrir[1], Carolyn Butler[2],
James Collins[2], Marta Fenn[2], Amy Jo Scarino[2], Cynthia Randles[3],
Pete Colarco[3], Arlindo daSilva[3], James Campbell[4],
Angela Benedetti[5], Samuel Remy[6]**

**[1]NASA Langley Research Center, Hampton, VA USA**

**[2]SSAI, Hampton, VA USA**

**[3]NASA Goddard Space Flight Center, Greenbelt, MD USA**

**[4]U.S. Naval Research Laboratory, Monterey, CA USA**

**[5]ECMWF, Shinfield Park, Reading Berkshire, UK**

**[6]Laboratoire de Météorologie Dynamique, Paris, France**

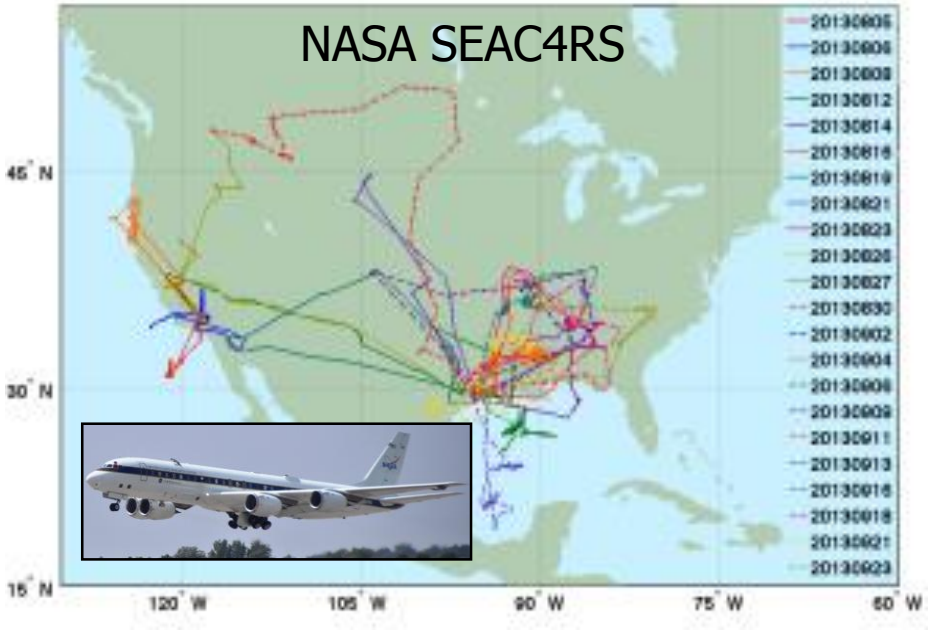
# Motivation and Objective

- Operational weather forecast centers (e.g. NRL, ECWMF, NCEP, etc.) are developing and testing schemes for assimilating MODIS and CALIOP data into forecast models
- Model evaluations have relied on AERONET AOT; however, correctly forecasting AOT does not necessarily imply correctly forecasting aerosol composition and/or vertical distribution which are important for applications such as air quality
- Evaluating model results that assimilate CALIOP data require independent, accurate lidar measurements

➢ **Objective: Use DIAL/HSRL aerosol measurements to assess and hopefully improve aerosol data assimilation systems**

# Airborne Ozone DIAL/HSRL System

- Ozone Differential Absorption Lidar (DIAL)
- Aerosol/cloud High Spectral Resolution Lidar (HSRL)
- Simultaneous Nadir and Zenith Measurements
- Resolutions:
  - Extinction: 1 min (~12 km), 270 m
  - Backscatter/Depol: 10 sec (~2 km), 30 m




**Profile Measurements:**

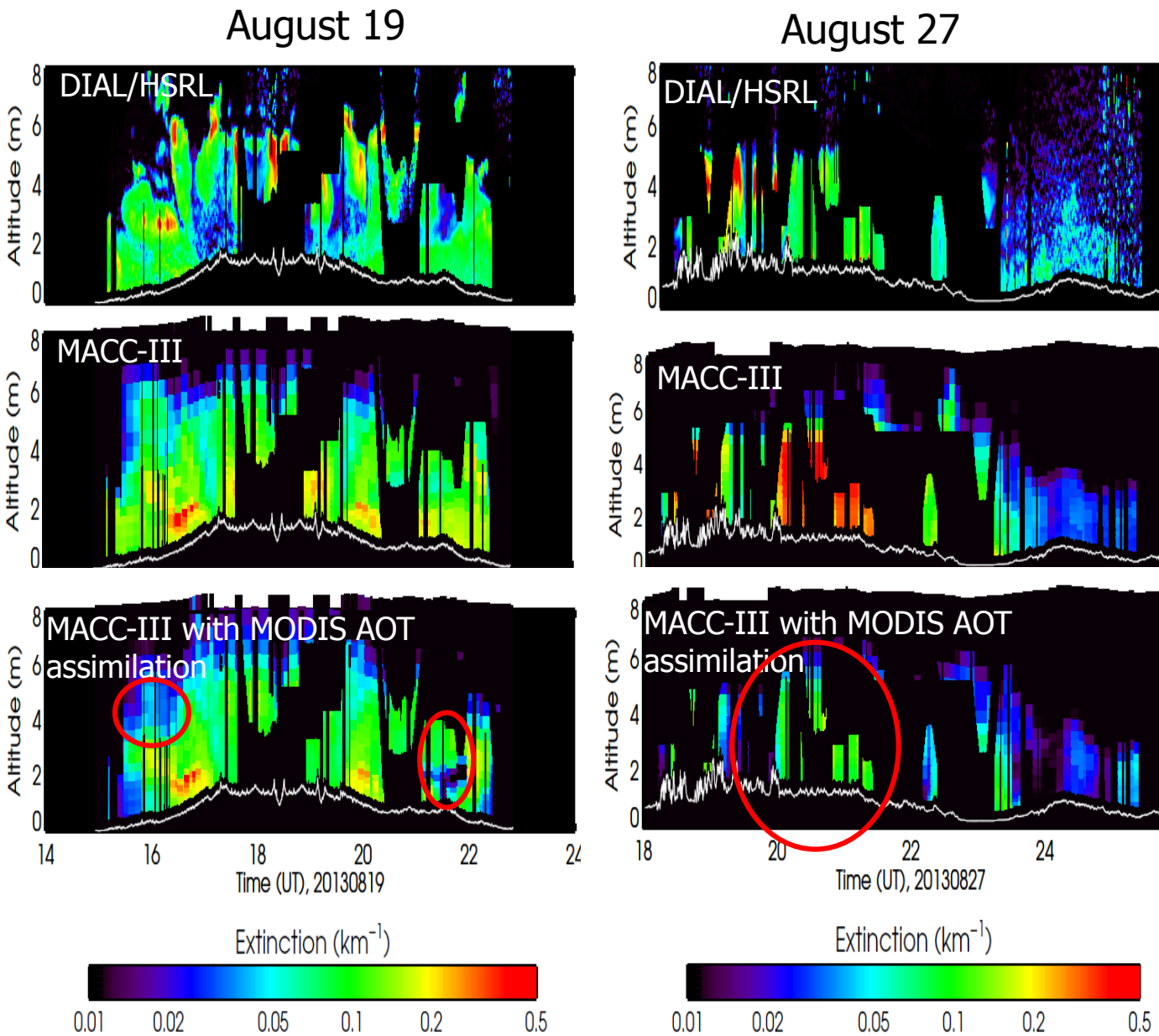
- **Ozone**
- **Aerosol Extinction (532nm)**
- **Layer AOT, AOT at 532nm (from aircraft altitude)**
- **Aerosol/Cloud Backscatter (532,1064nm)**
- **Backscatter Color Ratio (1064/532nm)**
- **Lidar Ratio (extinction/backscatter) (532nm)**
- **Aerosol/Cloud Depolarization (532,1064nm)**
- **Spectral Depolarization Ratio (1064/532nm)**
- **Mixed Layer Heights**
- **Aerosol Classification**

# Preliminary DIAL/HSRL Comparisons with ECMWF/MACC-III During SEAC4RS

# ECMWF/MACC-III Model

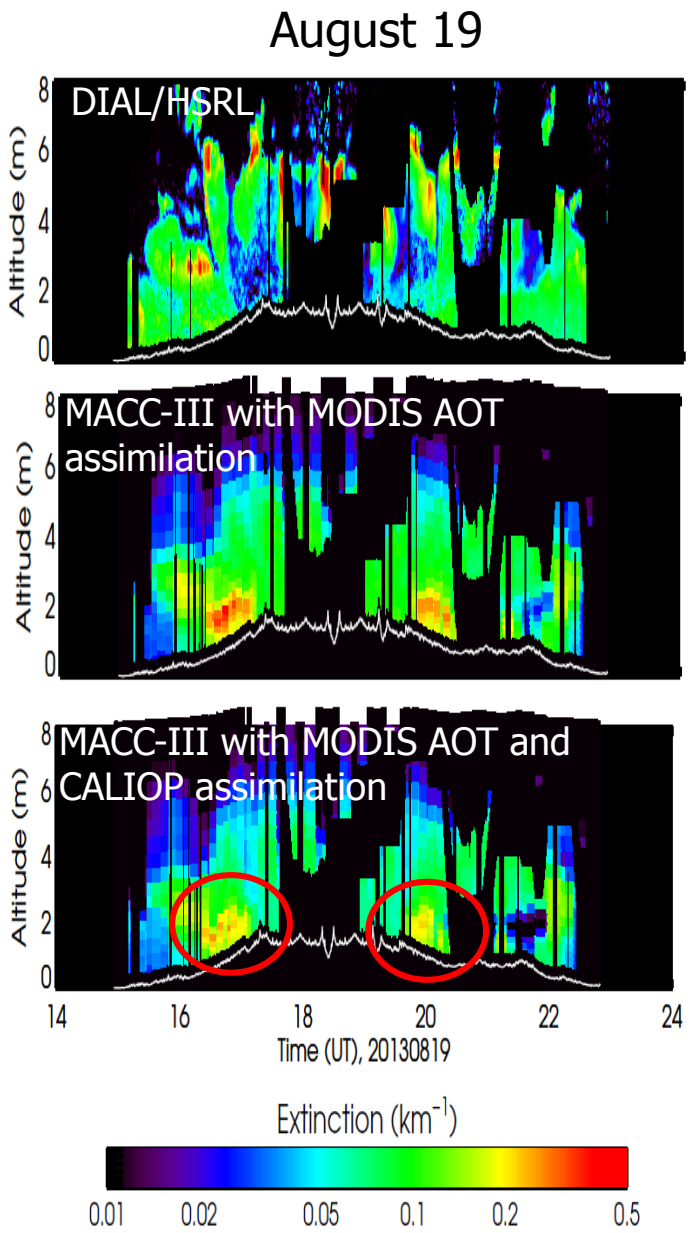
- Monitoring Atmospheric Composition and Climate-Interim Implementation (MACC-III) Model
  - Provides information regarding air quality, global atmospheric composition, climate forcing, solar energy
  - Consumers include WMO, EPA and European Centers, weather services, solar irradiance forecast groups, field campaigns
- Aerosol model has components for dust, sea salt, organic matter, black carbon, sulfate
- Eleven prognostic aerosol variables and one for $SO_2$
- Aerosol sources taken from
  - Global Fire Assimilation System (GFAS) (Kaiser et al., Biogeosciences, 2012)
  - Sea salt and dust – emissions computed online in aerosol model using met parameters
  - BC, $SO_2$, OM - Emission Database for Global Atmospheric Research (EDGAR)
- Resolution
  - Horizontal: T255 (~80 km)
  - Vertical: 60 layers
- Aerosol Data Assimilation
  - Terra/Aqua MODIS AOT
  - Working towards assimilation of CALIOP aerosol profiles
- MACC-III 3-hourly results from a series of experiments are examined here
- **SEAC4RS DIAL/HSRL data used to examine impacts of:**
  - **Assimilation of CALIOP data**
  - **Increased model resolution**
  - **Plume rise model impact on smoke injection heights**

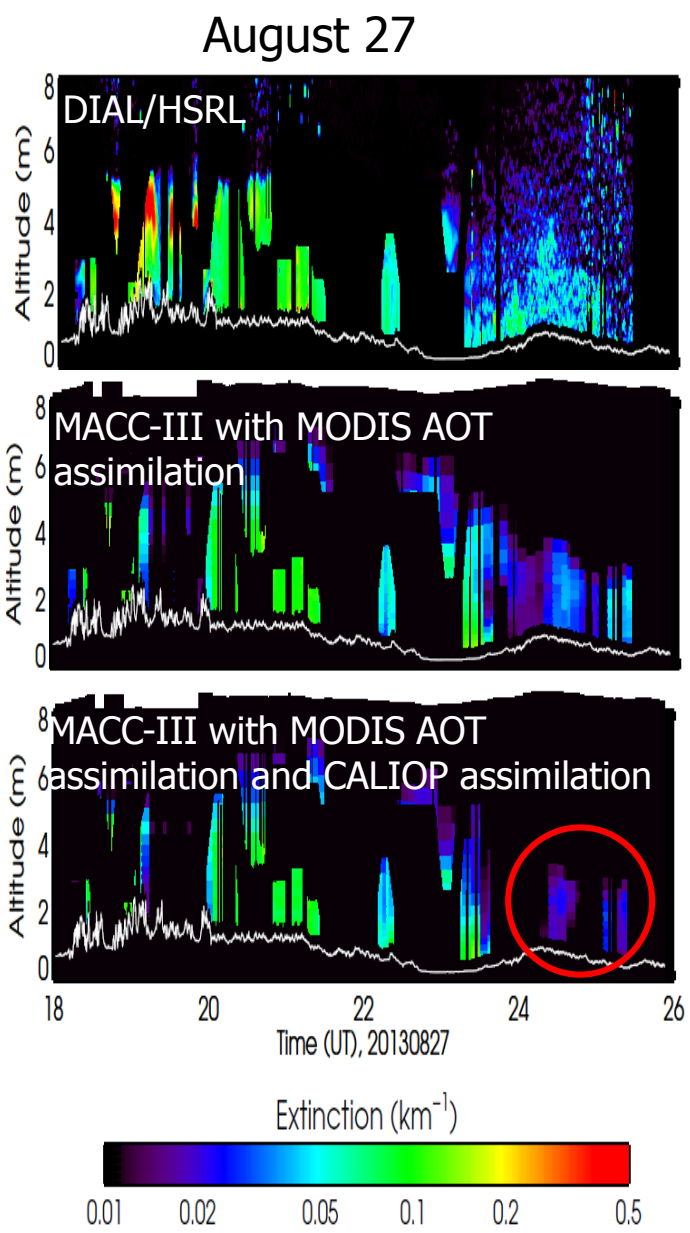
# Evaluating the impacts of MODIS AOT assimilation




- Aug. 19 case had extensive smoke layers from CA, OR, ID fires
- Aug. 27 had Rim Fire smoke
- Assimilation of MODIS AOT reduces aerosol extinction profiles in some sections of these flights
- Reductions in aerosol extinction vary with altitude

# Evaluating the impacts of CALIOP profile assimilation

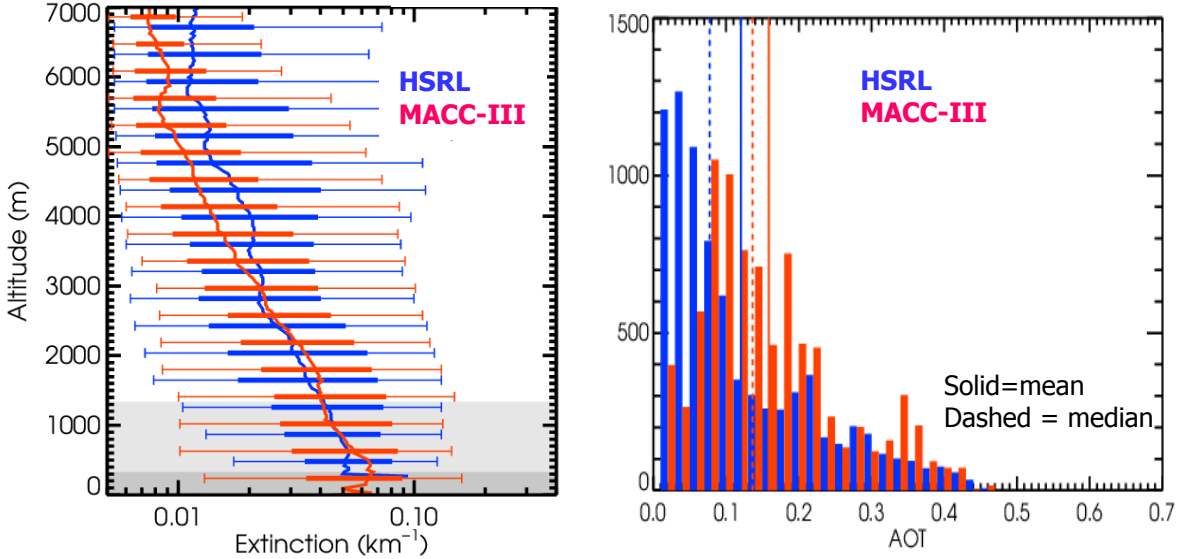


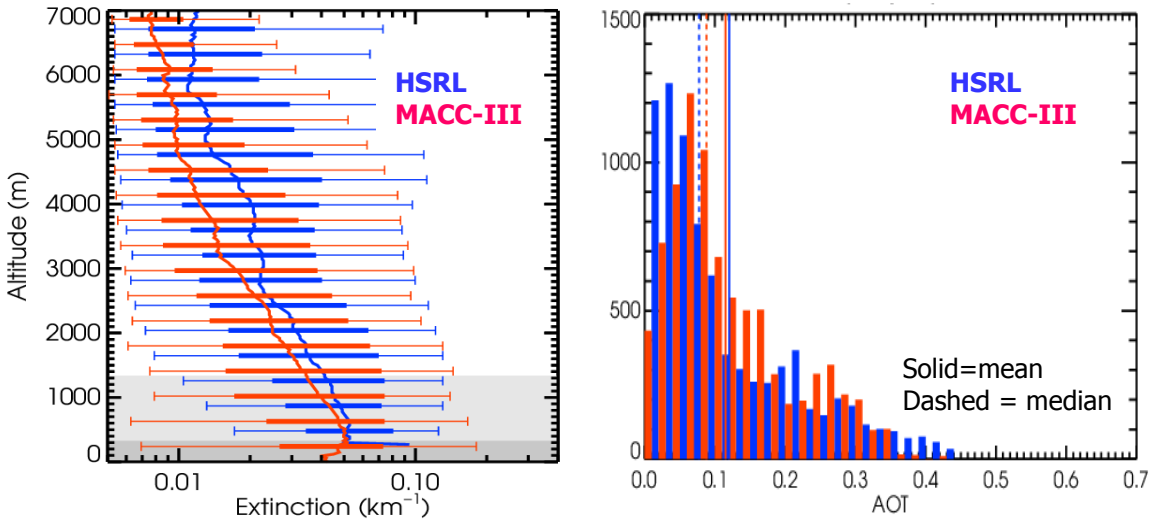

- Assimilation of CALIOP profiles slightly reduces extinction profiles in some locations; largest extinction values remain near surface
- Depending on location, these reductions can improve or worsen agreement with HSRL

# Comparison of Median Profiles with and without CALIOP assimilation

MODIS assimilation only

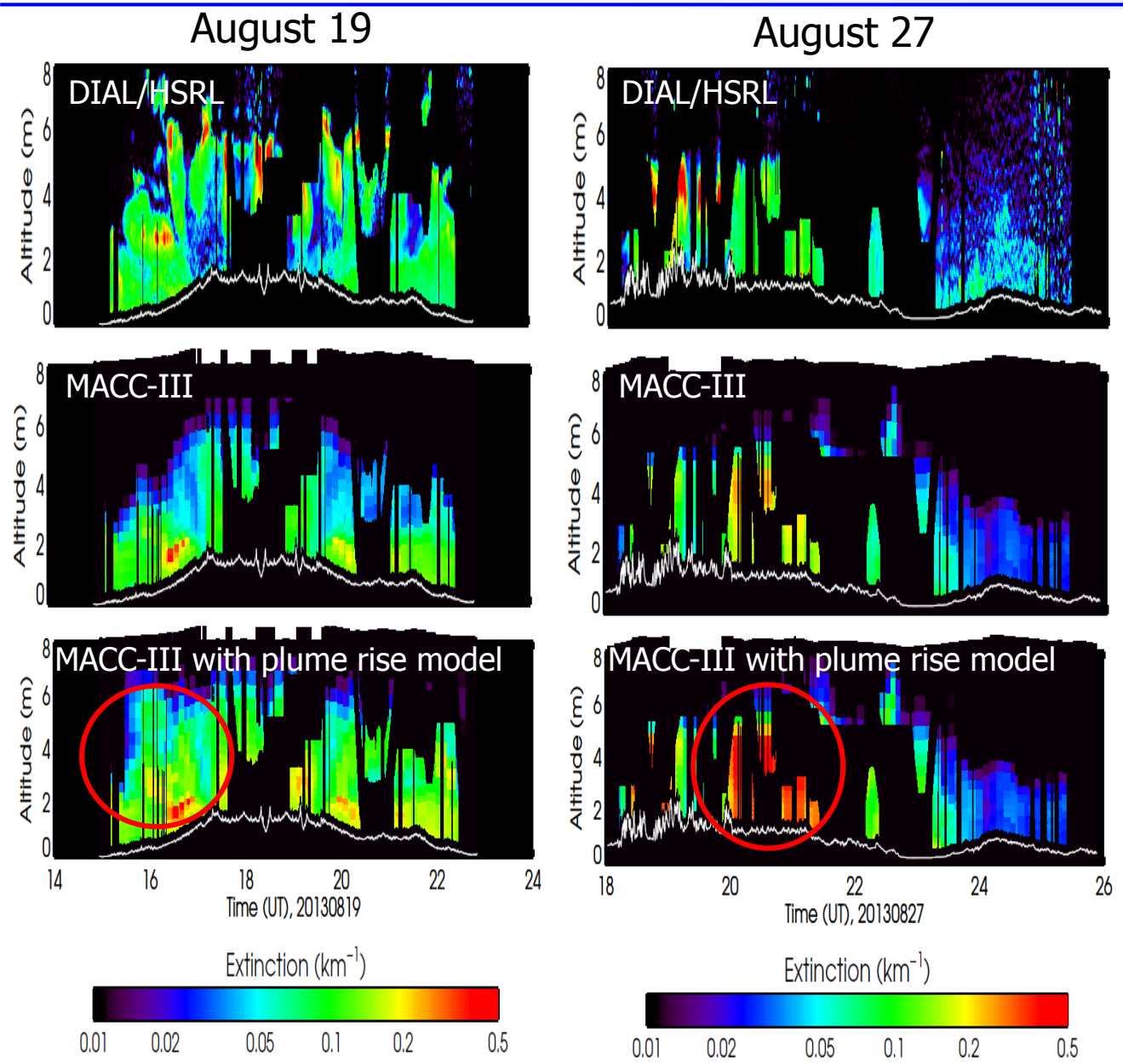



MODIS and CALIOP assimilation



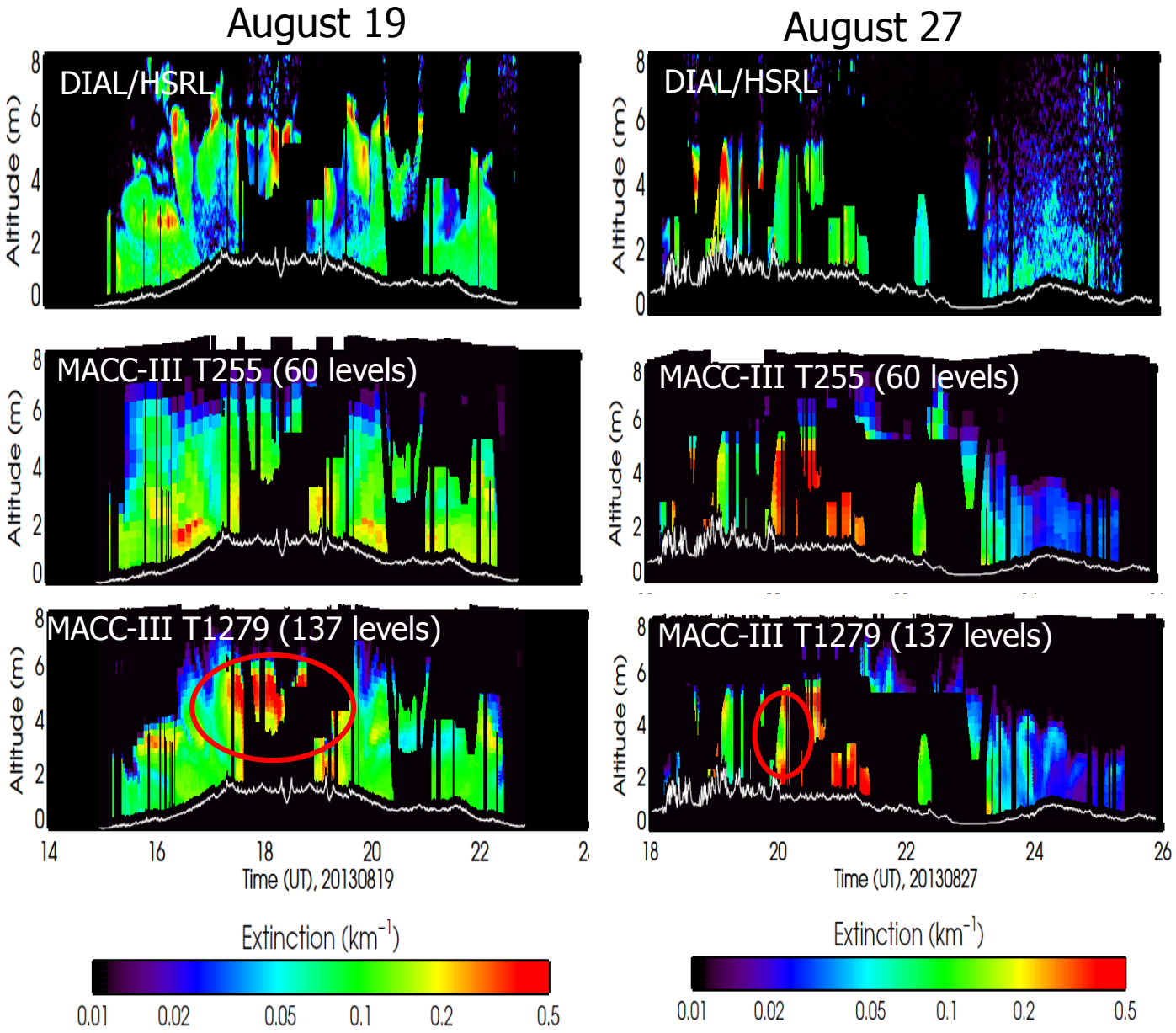

- Median profiles and histograms for entire mission
- Median profiles in good agreement with MODIS AOT assimilation
- Adding CALIOP:
  - produces relatively minor effects on median profiles
  - tends to lower the AOT with respect to runs that assimilate only MODIS AOT – slightly better agreement with HSRL

# Evaluating the impacts of smoke injection heights computed from plume rise model




- Injection heights for smoke emissions are estimated using Plume rise model (Paugam et al., 2015, in preparation, based on Freitas et al., 2007)
- This plume rise model uses MODIS FRP and modelled atmospheric profiles with a shallow convection scheme to represent detrainment from fire plume
- Initial comparisons show that both aerosol extinction and AOT increase throughout the profile, not necessarily at smoke height shown in DIAL/HSRL profile

# Evaluating the impact of higher model resolution




- Model resolution increased from T255 (80 km) with 60 vertical levels to T1279 (16 km) with 137 vertical levels
- Higher resolution represents smoke altitude better than assimilating MODIS AOT or using plume rise model

# DIAL/HSRL Comparisons with GEOS-5 During SEAC4RS

# GEOS-5 Atmospheric Data Assimilation System

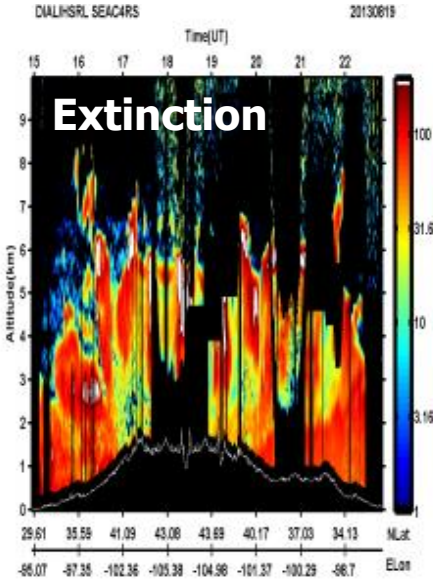
- GEOS-5 Earth Modeling System, GOCART aerosol module
- Five non-interactive species - dust, sea salt, BC, OC, sulfate
- Convective and large scale wet removal
- Dry deposition and sedimentation
- Optics based on OPAC model (Nonspherical Dust) from Colarco; Kim
- Fire emissions – Quick Fire Emission Dataset (QFED)
  - Based on MODIS Fire Radiative Power
  - Emission factors tuned using MODIS AOT
  - Daily mean emissions
- Aerosol Data Assimilation
  - Terra/Aqua MODIS AOT
  - MISR AOT over bright surfaces
- Resolution
  - Horizontal: 25 km
  - Vertical: 72 layers

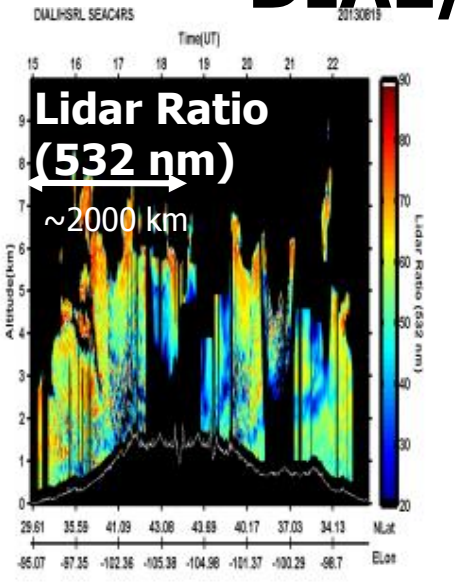
| | |
|---|---|
| dust | wind and topographic source, 5 mass bins |
| sea salt | wind driven source, 5 mass bins |
| black carbon | anthropogenic and wildfire source, mass hydrophic and hydrophilic |
| organic carbon | anthropogenic, biogenic, and wildfire source, mass hydrophic and hydrophilic |
| sulfate | anthropogenic and wildfire source of SO2, oxidation to SO4 mass |

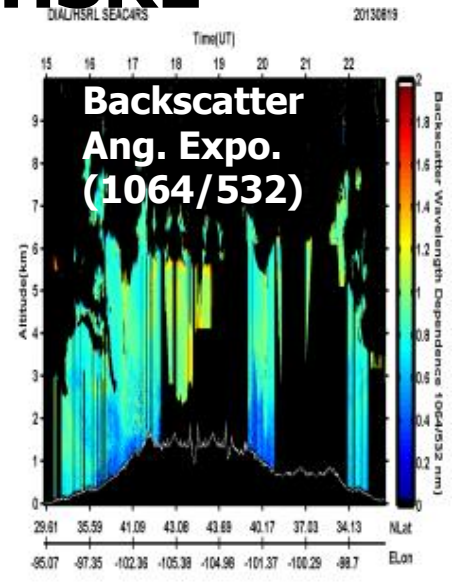
- PBL heights defined when diffusion coefficient falls below threshold
- **GEOS-5 3-hourly results from SEAC4RS reanalysis are examined here**

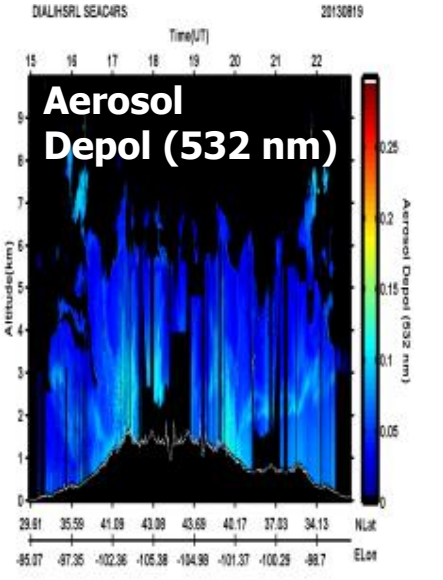
# SEAC4RS Aug. 19, 2013 DIAL/HSRL Smoke flight over Midwest

## DIAL/HSRL

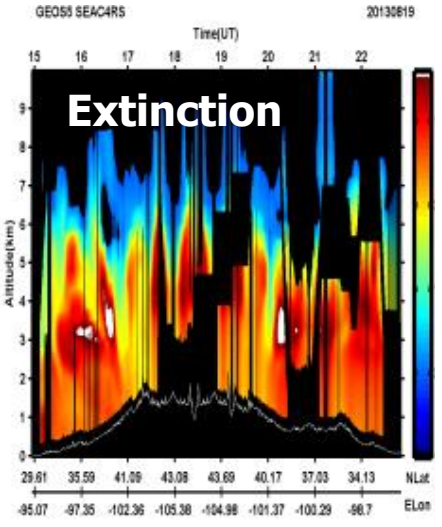


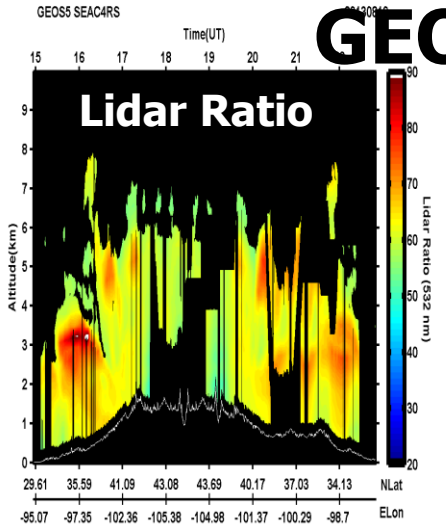



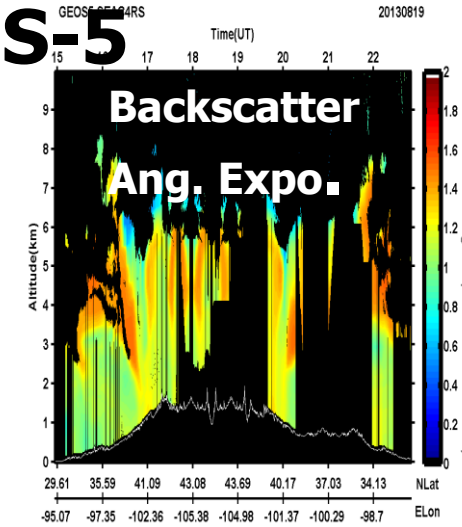



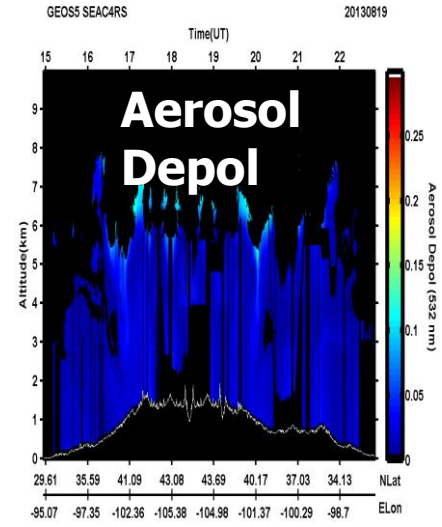




## GEOS-5



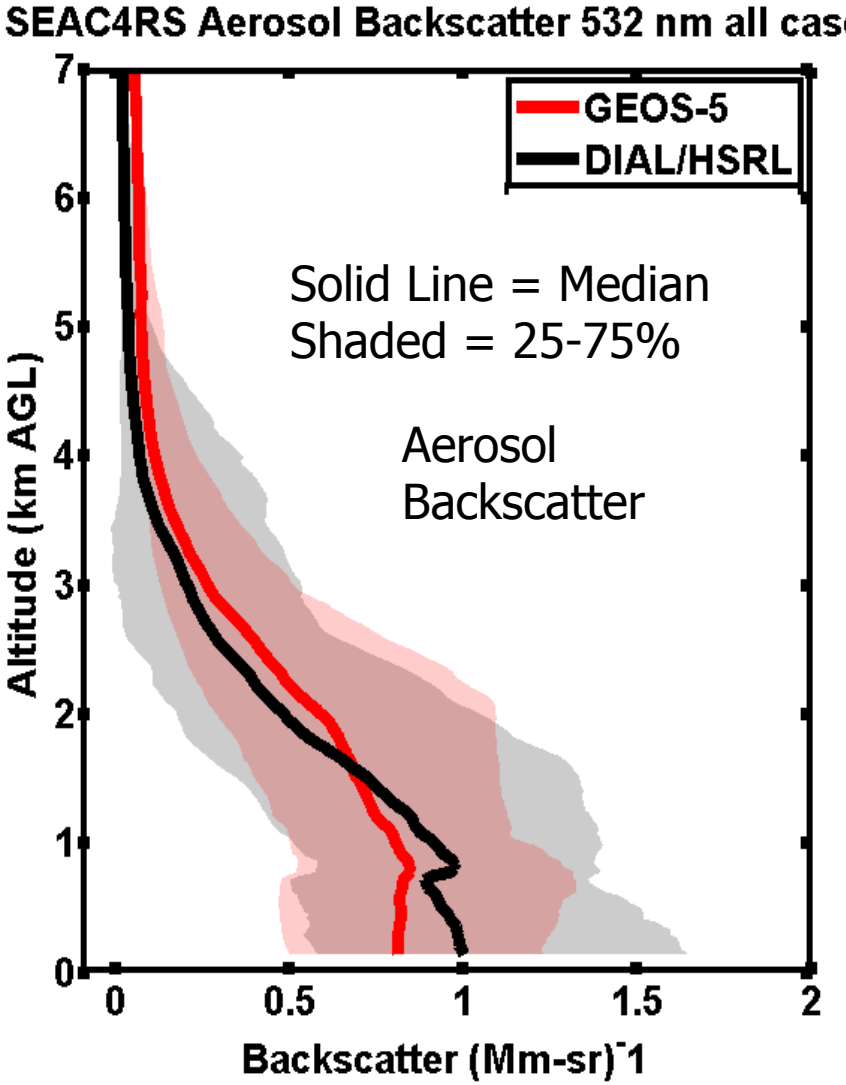



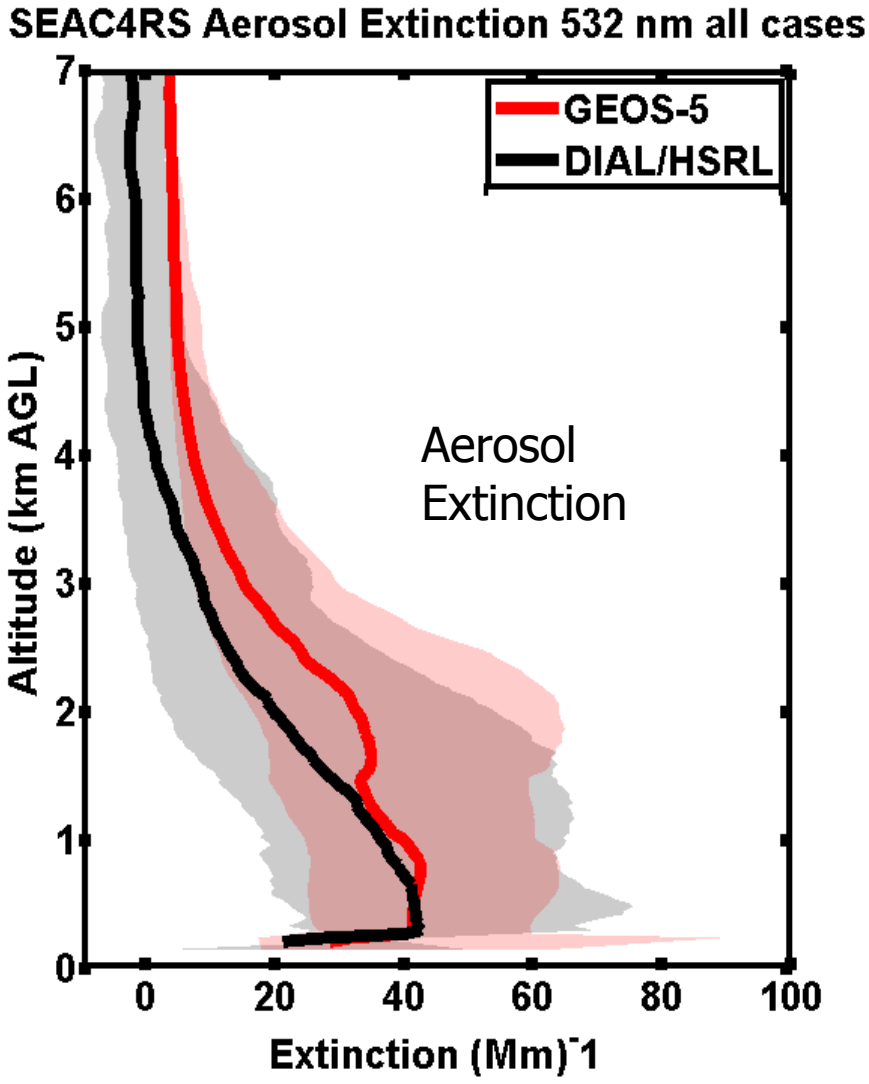



# DIAL/HSRL and GEOS-5 Median Backscatter and Extinction Profiles During SEAC4RS

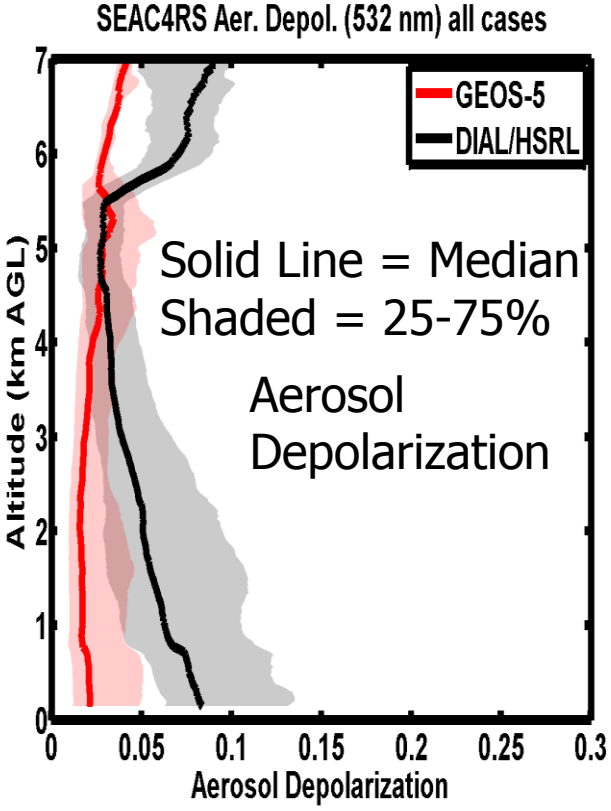
GEOS-5 shows slightly higher backscatter and extinction in free troposphere

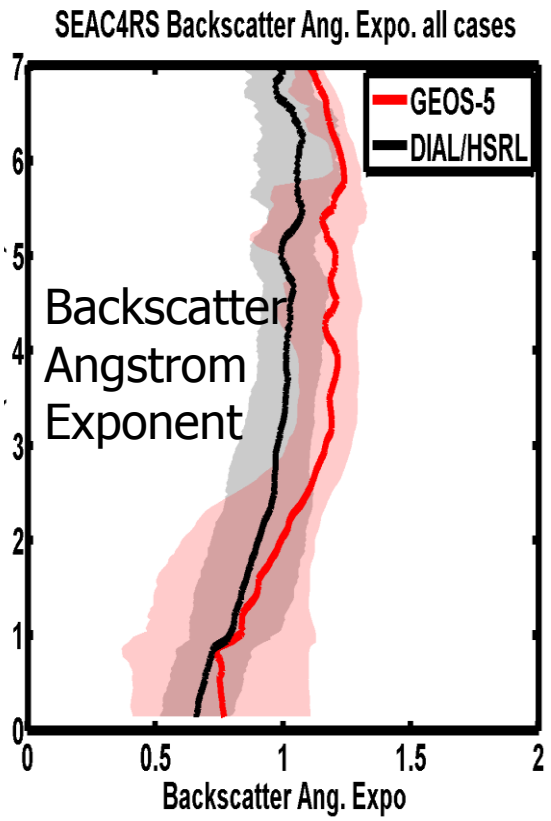


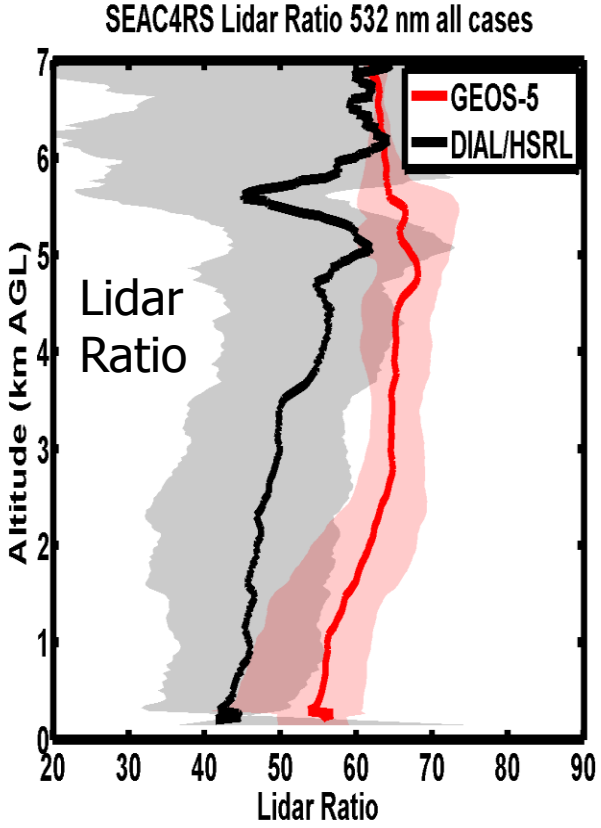



# DIAL/HSRL and GEOS-5 Median Intensive Parameter Profiles During SEAC4RS

- Both DIAL/HSRL and GEOS-5 intensive parameters vary with altitude suggesting aerosol type varies with altitude
- Backscatter Angstrom exponent increasing with altitude suggests decreasing particle size with height
- GOES-5 lidar ratio higher than DIAL/HSRL
- DIAL/HSRL measured more nonspherical particles (i.e. dust) near the surface than represented by GEOS-5

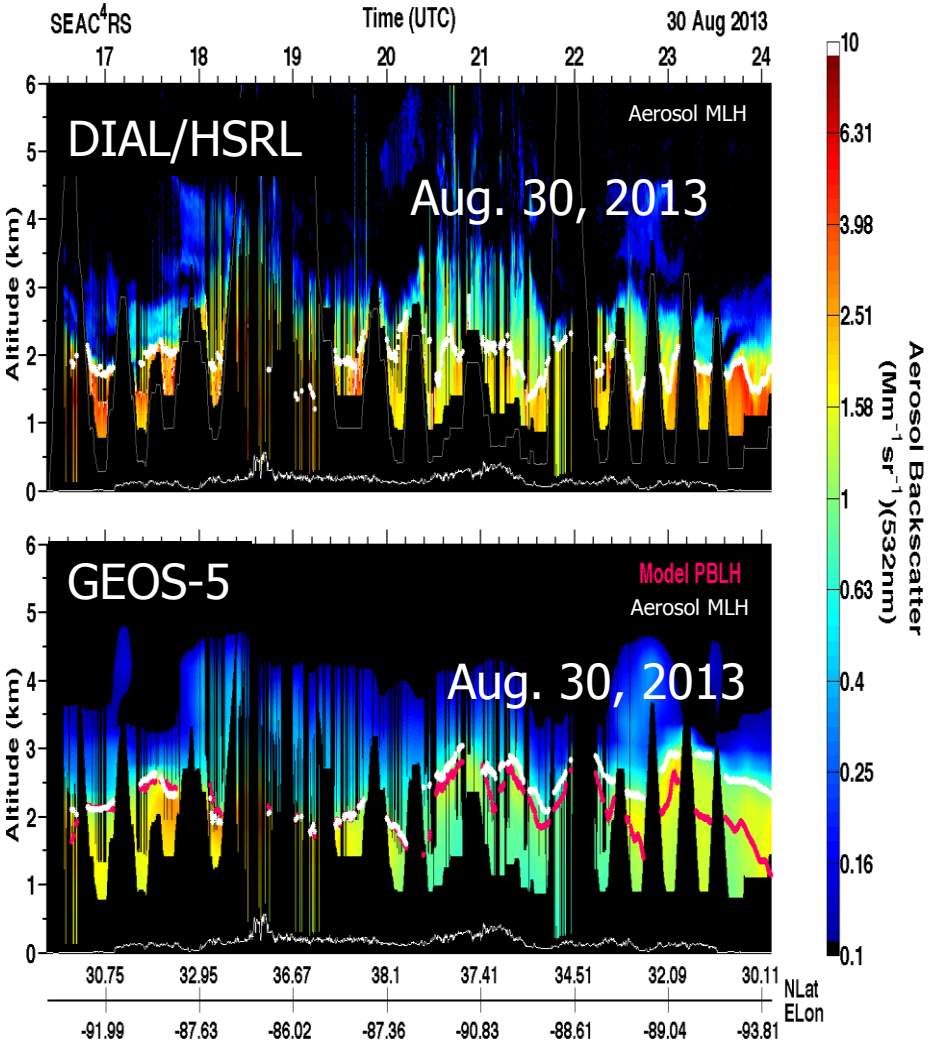


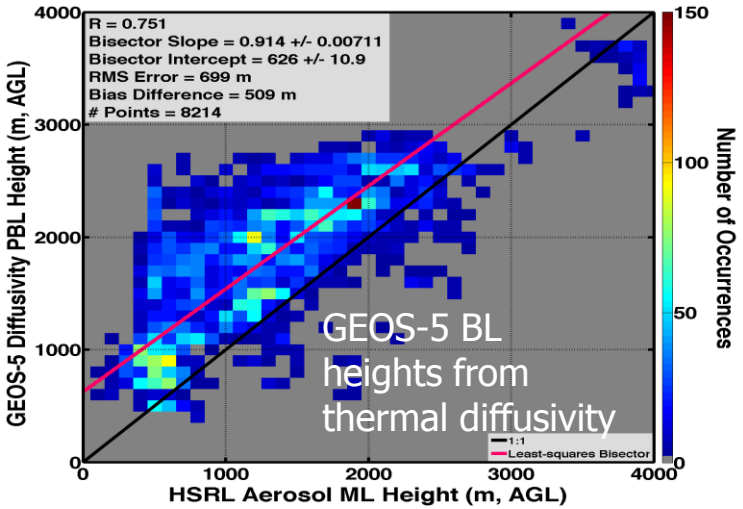



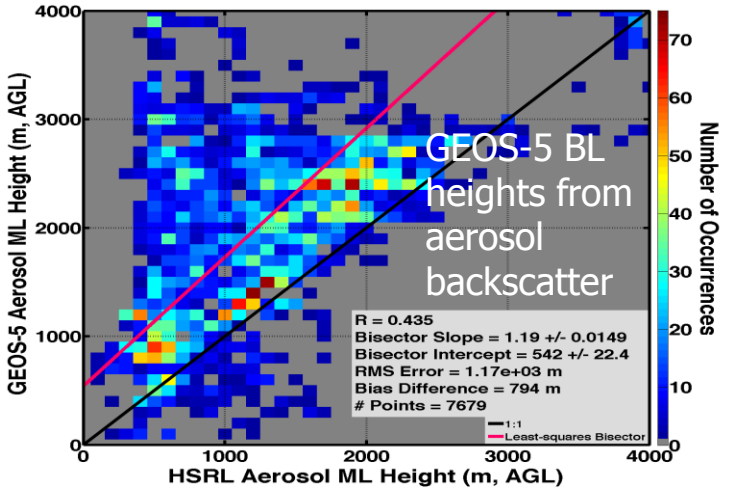



# Comparison of Boundary Layer Heights from HSRL-2 and GEOS-5 during SEAC4RS

- DIAL/HSRL boundary layer heights from aerosol backscatter gradients
- GEOS-5 boundary layer heights from thermal diffusivity and aerosol backscatter gradients were about 500-600 m higher than those derived from HSRL-2 and DIAL/HSRL



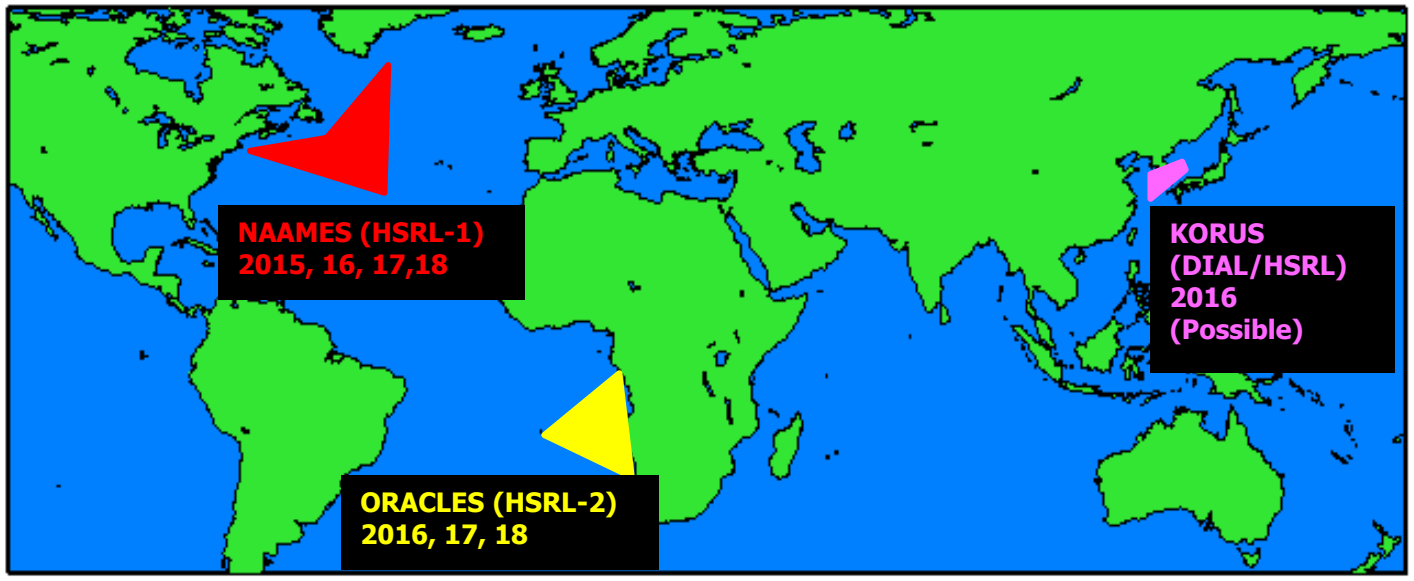
# Summary

- **HSRL measurements of aerosol extensive and intensive parameters provide additional constraints for developing and assessing models**

- Median ECMWF/MACC-II model extinction profile in agreement with median DIAL/HSRL profile
- Increased model resolution improves agreement with DIAL/HSRL profiles
- Initial comparisons with DIAL/HSRL show MACC-III assimilation of CALIOP profiles has relatively minor impacts on comparisons with DIAL/HSRL
- On average, GEOS-5 profiles of aerosol extinction and backscatter are in good agreement with HSRL measurements
- GEOS-5 simulations of aerosol depolarization are biased low – model misses local dust
- Both GEOS-5 and airborne HSRL data show aerosol intensive properties vary with altitude during SEAC4RS – likely due to smoke aloft
- GEOS-5 boundary layer heights are biased 500 m high relative to heights derived from airborne lidar data

# Current/Future Work and Future Measurements

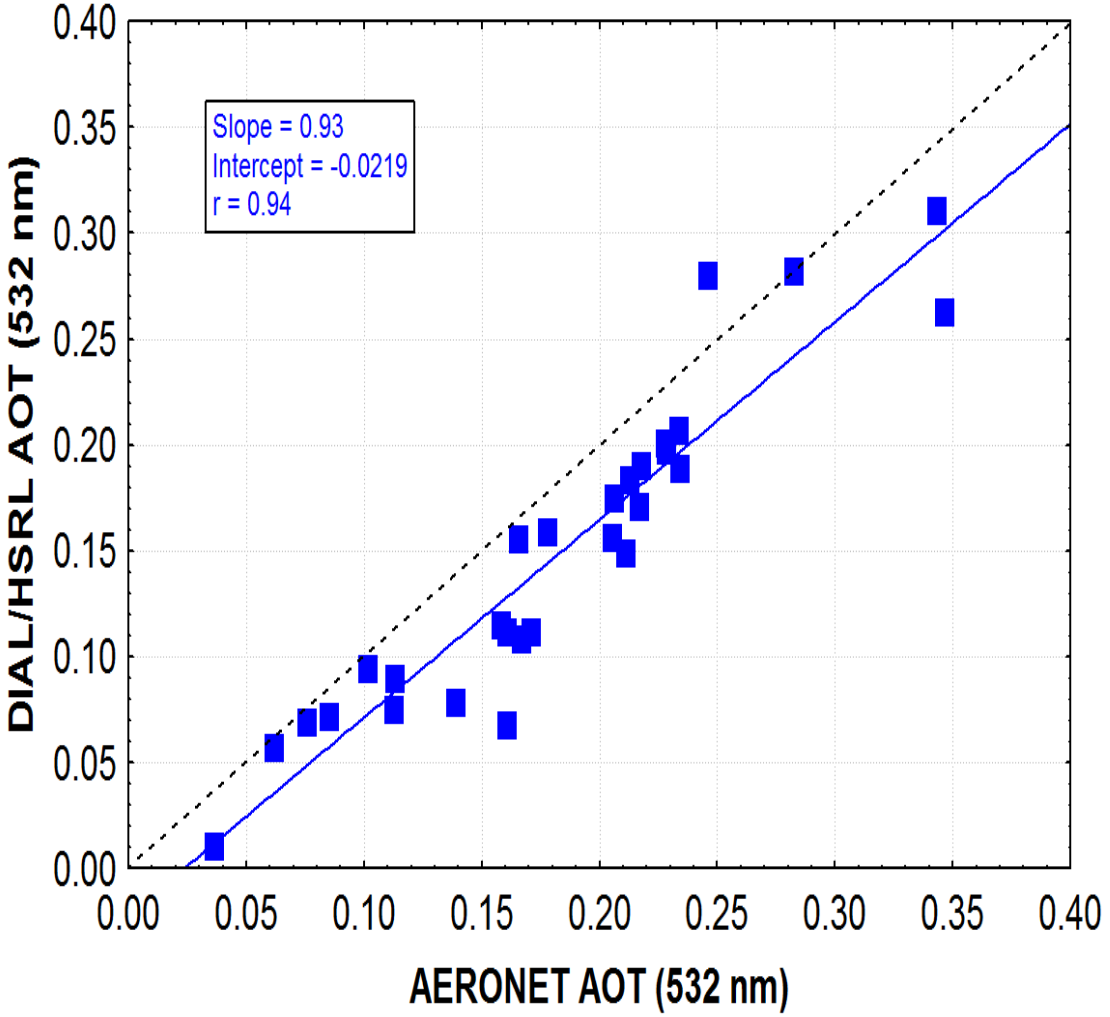
- Compare HSRL measurements with NAAPS Model
- Evaluate model representations of aerosol type
- Investigate impacts of model representations of dust and smoke particle shape on HSRL measurements of intensive properties
- Investigate use of HSRL-2 retrievals of aerosol properties (e.g. effective radius, concentration) for model evaluation
- Extend comparisons using airborne HSRL data acquired in future NASA missions



# Extra Slides

# DIAL/HSRL AOT comparison with AERONET

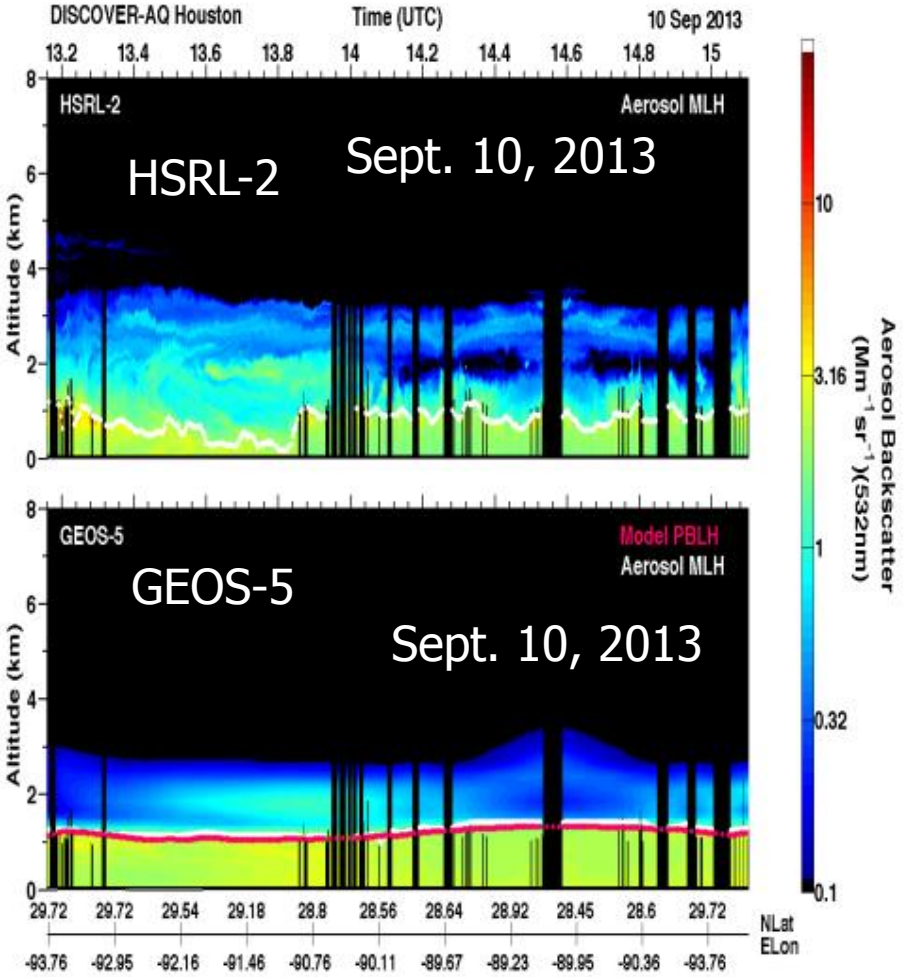
- AOT derived from DIAL/HSRL nadir data when DC-8 flew at or above 5 km
- AOT compared with AERONET level 2.0 AOT within 15 km, 30 min
- DIAL/HSRL AOT slightly lower than AERONET, possibly due to AOT not included above (> 5 km) or below (<150 m) profile

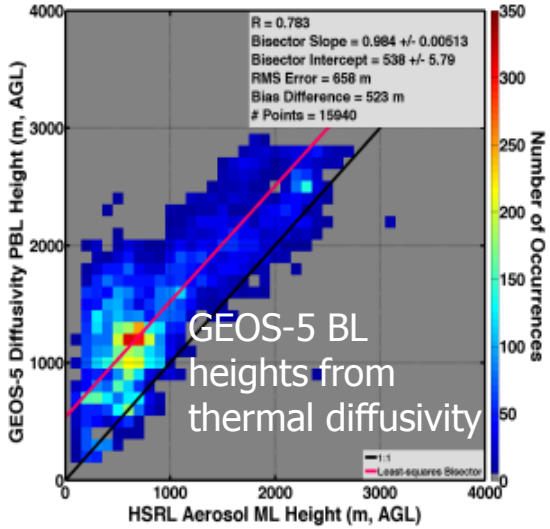


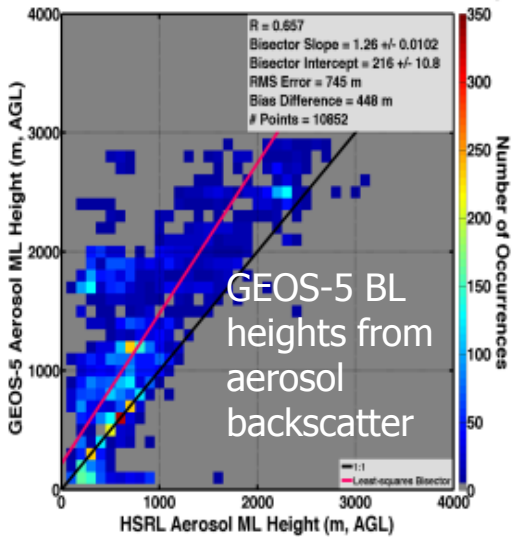

AERONET data – thanks to Brent Holben, Rick Wagener, Joe Shaw, Kevin Repasky, Kevin Knupp, Doug Moore

# Comparison of Boundary Layer Heights from HSRL-2 and GEOS-5 during DISCOVER-AQ

- HSRL-2 boundary layer heights from aerosol backscatter gradients
- GEOS-5 boundary layer heights from thermal diffusivity and aerosol backscatter gradients were about 450-500 m higher than those derived from HSRL-2 and DIAL/HSRL




(see Scarino et al., poster A31C-3040 Wed. AM for more details)

# NASA LaRC airborne HSRL systems have acquired extensive datasets over North America

- HSRL-1, HSRL-2, DIAL/HSRL have acquired science data on more than 450 flights (1500 hours) since 2006
- Data from three missions (DOE TCAP, NASA DISCOVER-AQ, NASA SEAC4RS) discussed here